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CHEMICAL RESEARCH, DEVELOPMENT & ENGINEERING CENTER

CRDEC-CR-103

UNIVERSAL LAUNCHER SYSTEM

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The design, fabrication and operation of a Universal Air Gun Launcher System (UAGL) is described. The UAGL uses pressurized inert gas rather than pyrotechnics to launch a wide variety of projectiles. The UAGL is a two-man portable system which is capable of launching a 30-lb projectile at a muzzle velocity of 200 ft/s from launch angles of -15 to 105 degrees.

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PREFACE

The work described in this report was authorized under Contract No. DAAA15-87-D-0019, Project No. 1119. This work was started in September 1987 and completed in January 1990.

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I. INTRODUCTION

The intent of the Universal Launch System program was to design and fabricate a prototype unit with the demonstrated capability of launching projectiles using pressurized inert gas rather then pyrotechnics as the projectile charge. The launcher was to be developed, based on the following design parameters:

- possess the capability of launching a 30 pound projectile to a height of 450 feet when 450 feet down range

- at design pressures, achieve a muzzle velocity of 200 feet/second

- designed and tested to withstand loads associated with pressurization to 1,000 psig

- operate at a nominal pressure of 500 psig

- the barrel was to be 43 inches long with a 5.75 inch I.D., fabricated from stainless steel, and removable from the charging tank

- the barrel was to be vertically adjustable from 15° below horizontal to 105° above horizontal (15° past vertical)

- the launcher was to be adjustable through 120° in the horizontal plane

- the system was required to be designed for easy disassembly with each part capable of fitting through a 2' x 4' opening

- the system was designed to use nitrogen as the charging gas

- the charging tank was to have a useable internal volume of 1,500 cubic inches

- provide a charging tank with a quick disconnect valve to facilitate pressurization from standard nitrogen bottles.

- a plunger type valve, activated by a 24 VDC solenoid was to be used as the

- the valve was required to fully open in no more then 100 milliseconds.

- a pressure gauge was required to measure the internal tank pressure

In addition, a level 1 drawing package was required for submission. After approval, a unit was produced from the level 1 drawing package.

In conjunction with design phase, a safety hazard analysis was performed. Findings of the PHA (Preliminary Hazards Analysis) were incorporated into the drawing package prior to fabrication.

II. HARDWARE DESCRIPTION

The launcher consists of three major sub-assemblies; the charging tank, barrel and base support, and can be easily disassembled with common hand tools and a strap wrench (for barrel removal). When disassembled, each component will fit through a 2' x 4' opening.

A. Charging Tank

The charging tank is constructed of carbon steel pipe and two rounded end caps welded to the pipe ends. Various fittings, to accommodate the pressure and purge solenoids and pressure gauge are provided. The tank components are designed to withstand loads generated by pressurization to 1,250 psig.

Housed inside of the tank is the firing mechanism. The tank also provides approximately 1,500 cubic inches of charging volume.

Internal to the tank is a large piston that, when shifted, allows the pressurized gas to enter the barrel at a high rate of speed. Forces created by the compressed gas causes the projectile to exit the barrel. At the rear of the tank, there is a small chamber. When the chamber is pressurized, the piston is forced forward The opposite end of the piston is shaped like a cup and seals the tank from the barrel. In firing the Universal Launch System, gas in the piston chamber is expelled, at a high rate, through a large orifice solenoid valve fitted on the back of the tank. The gas pressure in the tank forces the piston to move backwards, opening the tank to the barrel. The gas pressure is then released into the barrel, forcing the projectile out.

Pressurizing the tank is literally accomplished through the piston. The piston contains a 0.219 inch diameter port which allows gas to flow from the chamber, through the piston, out of the piston rod, and into the tank. A check valve located on the piston rod (in the flow path) prevents the backflow of gas into the chamber. Gas first enters into the piston chamber through a solenoid valve. Once the piston chamber is filled to the cracking pressure of the check valve, gas is allowed to enter the tank. A pressure gauge mounted through the vessel wall indicates the internal tank pressure.

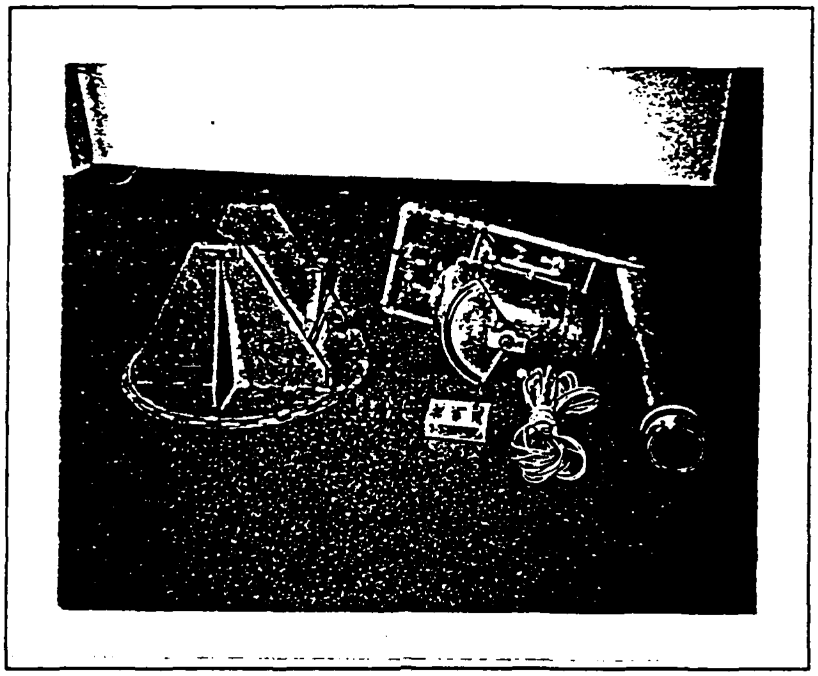
B. Barrel Assembly

The barrel assembly consists of 43 inch long, 5.75 inch I.D. stainless steel cylinder. One end of the barrel is threaded to allow assembly to the charging tank. The barrel is equipped with a flange housing O-rings to provide a seal between the barrel and tank.

C. Base Support

The base support is a carbon steel weldment which supports the tank assembly. The support is provided with a pivot to allow lateral adjustment through 120°. The tank is mounted to the support through bearing blocks to allow adjustments in the barrel elevation from 15° below to 105° above horizontal.

III. LAUNCHER ASSEMBLY PROCEDURE (See Figure 3)



A. Launcher Base Mounting and Assembly Procedure.

1. Gently, lower the base support weldment onto the primary base aligning the bore of the spherical bearing, located in the center of the base support weldment, with the spherical bearing stud located in the center of the primary base. Attach the 7/8" - 9 nut to the spherical bearing stud.

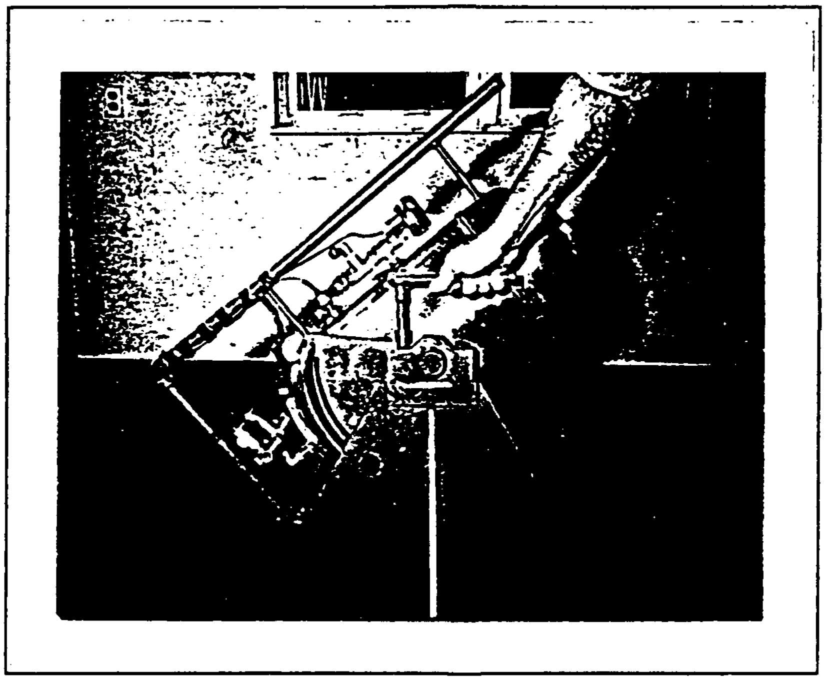
2. Attach the 7 anti-kick back blocks using two 1/4 - 20 UNC x 1.125" long cap screws provided for each block. Shim each block using two 1/4" bore washers per capscreen.

3 Mount the base assembly (primary base and base support weldment) to the desired mounting surface using four, grade 3, 1/2 - 16 UNC hex bolts, nuts and washers in the four - bolt hole locations around the perimeter of the primary base.

B. Tank Mounting and Assembly

1. Loosen, but do not remove the hex bolts securing the tilt guide plates to the tank so they may "wobble" freely.

2. Lower the tank onto the base support, aligning the bearing blocks with the mounting surface on the base support. Insert the four (4) 3/8 - 16 UNC x 2.5" long bolts and 3/8" lock washers into the bearing blocks. Do not tighten down the bolts until all four have been threaded into the base support.



3. Place the spacer between the base support upright and the tilt guide plate. Insert a 3/8 - 16 UNC x 2.5" long tee-slot bolt through the inside face of the tilt guide plate, through the spacer, and exiting through the 1/2" hole on the base support upright. Install the malleable ball handle and repeat for the other side. Tighten the hex bolts that attach the tilt guide plates to the tank.

C. Launcher Barrel Installation and Assembly

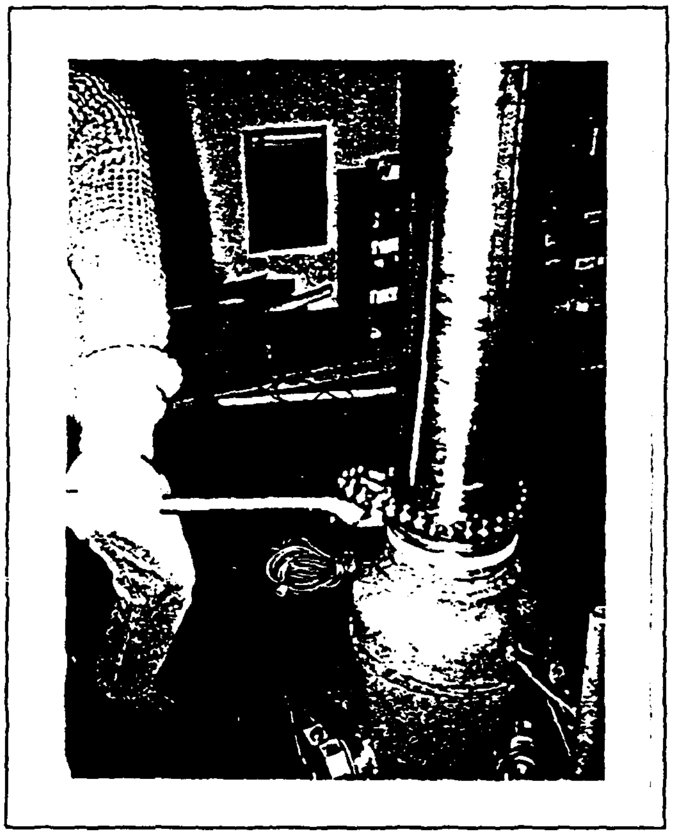
1. Verify that all o-rings and mating surfaces are thoroughly greased.

2. Carefully place the spacer ring, with the o-ring groove facing the same direction as the barrel o-ring grooves, over the barrel threads taking care not to skew the spacer ring. Skewing the spacer ring can cause it to bind on to the barrel threads. Slip the spacer ring all the way back until it butts against the outer barrel o-ring. Use any adhesive tape (masking tape, duct tape, etc.) to hold the ring in place during installation of barrel.

3. Loosen the ball handles and rotate the tank to the vertical position. Tighten the ball handles to hold the tank in position.

4. Place barrel on top of the charging tank. Install the barrel on the tank by rotating the barrel clockwise by hand until the barrel flange o-ring butts against the tank o-ring surface.

6. Using a strap/chain wrench, tighten the barrel until snug.



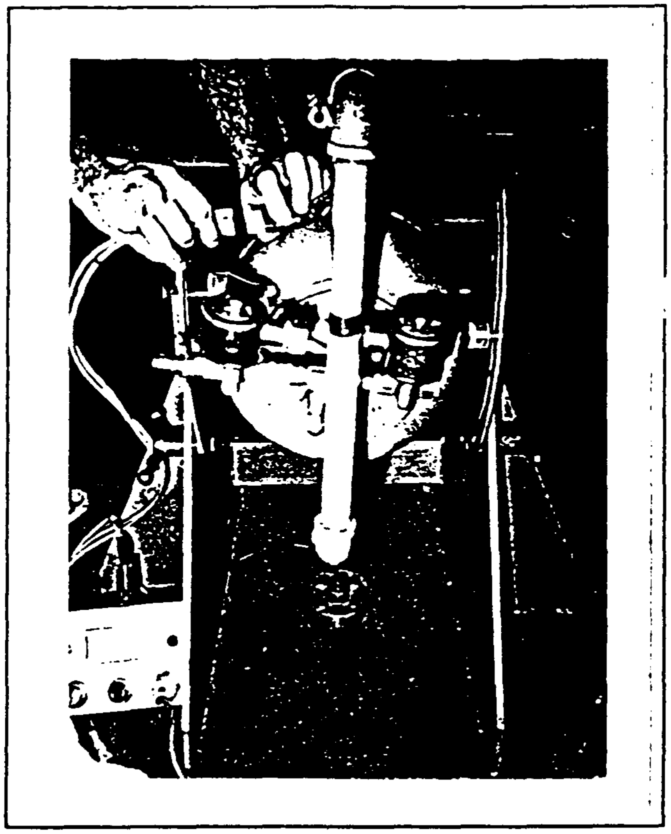
D. Launcher Controls Installation and Assembly

1. Connect the, white, 9-pin female cable connector to the 9-pin male connector on the launcher tank.

2. Attach the black, female, 10-pin cable connector to the control box.

3. Attach the remaining black and white leads, to any 24 VDC power supply or battery source.

4. With power applied the solenoid switches should be active and the meter should display 1.2 MV (this indicates a zero pressure reading).



5. To replace the 9V transistor radio battery located in the control box:

    a. Remove the bottom panel screws and panel
    b. Detach the battery clip
    c. Remove the battery
    d. Attach a new battery to the battery clip
    e. Secure the battery to the bottom panel where it won't interfere with any of the electrical components inside the control box using masking tape.
    f. Replace the bottom panel and screws.

PROCEDURE FOR DISASSEMBLY OF THE UNIVERSAL LAUNCH SYSTEM

1. To disassemble the Universal Launch System, reverse the procedure for the system assembly.

IV. OPERATING PROCEDURE

WARNING: THE UNIVERSAL LAUNCH SYSTEM SHOULD BE OPERATED ONLY BY PERSONNEL TRAINED IN THE SYSTEM OPERATION. FAILURE TO HEED THIS WARNING COULD RESULT IN SERIOUS PERSONAL INJURY.

During operation of the Universal Launch System, the following general guidelines should be adhered to:

- Never load the launcher barrel while the tank is pressurized.
- Verify that the key switch is turned counter clockwise to the "off" position before attempting to pressurize the tank.
- The launcher should be aimed and loaded before pressurizing the vessel.
- Keep the inside of the barrel and the outside of the projectile clean.
- Keep the barrel threads clean and protected during assembly and disassembly operations.
- The launcher should be kept dry to prevent corrosion.
- Verify that all personnel are clear of the firing area before pressurizing the tank.

A. System Requirements

The Universal Launch System requires a supply of nitrogen gas (N_2) for tank pressurization. A 1/4 NPT female fitting, rated to 1,000 psig, is required on the nitrogen supply for connection to the system quick disconnect charging port. In addition a 24 VDC power source is required for system controls.

B. Adjustments

The base support of the Universal Launch System is designed so that the system may be positioned at any angle of elevation between -15° and 105° from horizontal and adjusted through a lateral range of 120°. Adjusting the angle of elevation of the launcher is accomplished by loosening both ball handles on the upright main gussets of the base support weldment, positioning the barrel at the desired angle, and re-tightening the two ball handles. Lateral adjustment is accomplished by turning the gun, barrel and base support about the primary base. It should be noted that there are no end stops for the lateral adjustment and that the launcher is designed to be fired only with the barrel positioned within the specified 120° lateral range marked by the seven anti-kickback blocks located around the perimeter of the primary base. (Refer to Appendix **FIGURE** 1)

C. Projectile Loading

WARNING: THE TANK MUST BE AT AMBIENT PRESSURE PRIOR TO PROJECTILE LOADING. FAILURE TO HEED THIS WARNING COULD RESULT IN SERIOUS PERSONAL INJURY.

Because the projectile is gravity-fed to the firing position the launcher barrel should be inclined to at least 45° from horizontal. After placing the projectile in the barrel, the purge solenoid is opened to allow the air being displaced by the projectile moving into the barrel to escape. Note that upon loading the projectile the tank must be completely purged (at ambient pressure) of pressure prior to projectile loading.

D. Pressurization Procedure

WARNING: ALL PERSONNEL MUST BE CLEAR OF LAUNCHER PRIOR TO COMMENCING PRESSURIZATION AND FIRING PROCEDURES. FAILURE TO COMPLY WITH THIS WARNING COULD RESULT SERIOUS PERSONAL INJURY.

Once the quick disconnect has been connected and the nitrogen source initiated, the key (fire) switch is turned counter clockwise to the off position. Next the red (fill) switch is depressed on the control panel until the desired pressure reading from the pressure sensor is displayed. (Reference Appendix C for pressure vs voltage plot).

The tank pressure can be reduced or returned to ambient conditions by depressing the black purge switch until the desired pressure is achieved.

E. Projectile Launching

Firing of the launcher can be accomplished after loading the projectile and pressurizing the tank. The tank can only be pressurized <u>after</u> projectile loading is completed and all personnel are cleared from the area. Likewise, all personnel must remain cleared from the area during the launch sequence. It is further suggested that a countdown or another check-off process be established and conducted to make personnel aware that launching is imminent. To fire the launcher, turn the key clockwise. This will activate the firing solenoid, launching the projectile.

V. EXPERIMENTATION

Three tests were performed on the Universal Launch System; a hydrostatic testing of the tank at MRC in Hunt Valley, MD; a functional pre-test at the H.P. White Laboratories in Street, MD; and demonstration testing at CRDEC in Edgewood, MD. The hydrostatic testing at MRC was performed to safely establish that the vessel could be pressurized to the maximum specified levels (1,000 psig). The functional pre-testing was performed to demonstrate proper functioning of the system. The demonstration testing was performed to establish performance information about the ULS as well as to optimize its performance.

A. The Hydrostatic Test

Hydrostatic testing of the pressure tank was accomplished to demonstrate the tanks capability to survive loads associated with a 750 psig design pressure.

The procedure for the hydrostatic test was as follows. All, except two, of the ports on the vessel were sealed off. The vessel was filled with water leaving no air pockets. A hydraulic pressure line was fitted to one of the unsealed ports and a pressure gage fitted to the other. Hydraulic fluid was pumped into the line with a hydraulic pump. Pumping continued until the desired test pressure had been reached. The pressure was then reduced to ambient conditions.

The results of the hydrostatic testing were positive, however some design modifications had to be made before the vessel was approved. The vessel was tested three times before it passed.

During the first test, the pressure in the vessel was increased to 275 psig at which point a leak was detected. The leak occurred at the rear of the vessel in the end plate O-ring seal. Since the end plate is a male threaded part, it was assumed that it had not been secured. The pressure was reduced and the tank drained so that the O-ring could be checked for damage. The O-ring was undamaged so it was re-installed into the end plate. The end plate was then replaced into the vessel and tightly secured.

The results of the second test were also negative. The tank was refilled and the hoses reconnected. Again, the tank was pressurized and leaked at 275 psig. The pressure was again reduced and the O-ring was re-checked for damages. Again it was undamaged. Next the design was reviewed. It was found that the O-ring was being used inappropriately. Modifications were made to the launcher, and the O-ring reinstalled.

For the third test, pressure was increased to 1,200 psi, maintained for 15 minutes, and purged. No failures were noted.

B. Testing at H.P. White Laboratories

Testing completed at the H.P. White Laboratories was performed to demonstrate proper functioning of the Universal Launch System. During testing, the launcher was successfully fired four times. A cylindrical, 11 lb, high density polyethylene test slug was used for this phase of testing.

For the first launch, the test slug was loaded and the tank was pressurized to 100 psi. The launcher was elevated to 50 degrees and fired. The slug traveled approximately 500 feet. The estimated flight time of the test slug was 10 seconds.

For the second firing, the distance traveled and flight time were measured. The barrel elevation was 50 degrees and the tank was pressurized to 100 psi. The test slug traveled for 7.71 seconds and was recovered 622 feet down range.

It was estimated that to reach a height of 450 feet, the projectile would have to be airborne at least 10.6 seconds. For the third test, to increase the flight time without increasing pressure, the barrel elevation angle was raised to 55 degrees. With the tank pressurized to 100 psi and a 55 degree elevation angle, the projectile stayed aloft for 8.44 seconds and traveled a distance of 700 feet.

For the final test, the barrel angle was raised to 65 degrees. At 100 psi tank pressure, the test slug flew 548 feet for 9.38 seconds. Having verified proper functioning of the Universal Launch System, testing was concluded.

C. Final Testing and Demonstration at Edgewood

The purpose of this testing was to determine the capabilities of the Universal Launch System and in doing so, demonstrate that the system meets the contract requirements. The primary goal of the project was to launch a 30 lb spigot sabot 450 feet high when 450 feet down range. As specified contractually, a muzzle velocity of 200 ft/sec is theoretically required to attain this performance.

The major contract requirements are:

a Vertical adjustment of -15° below horizontal to 105° above horizontal

b Lateral adjustability of 120°

c Muzzle velocity of 200 ft/sec

d Launch a 30 lb spigot sabot 450 feet high when 450 feet down range

The launcher adjustability range, items "a" and "b" were demonstrated by inspection. The muzzle velocity of the projectile, requirement "c", was measured with a weibel, Model W-680 doppler radar. The range and height requirement item "d", was calculated based on the muzzle velocity and the launch inclination angle. The calculations used to determine the maximum height and range, S_{ymax} and S_{xmax} respectively are:

$$S_{ymax} = \frac{(Vo \sin \theta)^2}{2g} \quad \text{and}$$

$$S_{xmax} = \frac{2\, Vo^2 \sin \theta \cos \theta}{g}$$

(See Appendix A for derivation of formulas)

Where S_{xmax}, S_{ymax} = Range and height respectively, units are feet or meters

V_o = Muzzle velocity in ft/s or m/s

θ = Launch angle in degrees

g = Acceleration due to gravity in ft/s^2 or m/s^2

RESULTS

On 10 January, 1990, the Universal Launch System was successfully fired 7 times at the Edgewood Area of Aberdeen Proving Grounds, MD, starting at 100 psig and incrementally increasing pressure to 600 psig. Launch number five (5) fulfilled the contract requirements by using nitrogen gas to launch the 27 lb spigot sabot. The tank pressure was set at 600 psi and the trajectory launch angle was set at 55° above horizontal. The muzzle velocity measured by the radar was 75 m/s.. The calculated muzzle velocity predicted was, 78.7 m/s. From equations <29> and <69>, the height was calculated to be 479 feet, (at 450 ft down range) with a maximum elevation and range of S_{ymax} 631 ft. and S_{xmax} 1,768 ft. respectively.

After the fifth launch, two more launches were made to gather additional data. These tests yielded a drop in performance. *Upon inspection, the piston O-ring was found to be broken.* An O-ring of a different material, better able to withstand the adverse working parameters of pressure and temperature was selected and installed. On 27 February 1990, a final series of launch tests were performed at the Edgewood area of Aberdeen Proving Grounds, MD. A 27 lb. projectile (i.e., 20 lb projectile and 7 lb spigot sabot) was successfully launched 3 times through the required trajectory using a tank pressure of 400 psi. Thus, performing reliably, the Universal Launch System had been successfully demonstrated, satisfying all contractual requirements.

VI. DESIGN MODIFICATIONS, SUGGESTIONS, AND RECOMMENDATIONS

During the course of the ULS program, there were several modifications leading to the final design. Although most modifications were made during design, several were made during assembly and testing of the launcher. Many of the design modifications were deemed necessary to effect safe, proper functioning of the system. However, some were made either for convenience or to simplify the design.

* Purge Valve - Initially, the purge valve, used to purge the vessel was a manually operated unit. The valve was replaced with a solenoid valve to allow purging of the vessel to be accomplished remotely.

  The solenoid valve used to replace the purge valve had a 3/32 inch orifice. Because the opening is so small, an extended purge time was noted. A solenoid valve with a larger orifice could be used to reduce the time required to purge.

* Solenoid Firing Mechanism - A hydraulic, 3-way solenoid valve, was originally chosen to both fill the launcher with gas as well as fire the launcher by releasing the gas. The hydraulic valve was chosen because it was capable of higher pressures, however, it was discovered that the valve would not function safely with pneumatics. Because it was difficult to find an off-the-shelf pneumatic 3-way solenoid valve that was rated to the design specified pressure, two, two-way solenoid valves were used in junction with a branch tee. One solenoid valve was used to fill the vessel and the other to fire (actuate the launching mechanism) the launcher.

* External Check Valve - A check valve was added in the fill line, between the fill solenoid and the vessel, to prevent back-flow of the gas into the line when the solenoid valve was opened.

* Internal Check Valve/Tank Pressurization Orifice - The check valve originally chosen to allow gas to bleed into the vessel from the piston chamber (via the piston) was found to be undersized. This check valve caused lengthy fill periods. Thus, the tank pressurization orifice in the piston was increased from

a 10-32 UNF screw thread to a 1/4 NPT pipe thread. This allowed the inclusion of a larger check valve to reduce pressurization time.

* Fill/Fire Solenoid Valve Configuration - A quick disconnect was added so that the valves could easily be connected/disconnected to the tank. This was accomplished to reduce break down and re-assembly time of the launcher. Although this was not intended to be included in the final design, it did prove to be useful.

* Tilt Adjustment Handles - Originally, two hand knobs were specified for locking down the launcher at a desired angle. With these knobs, adequate torque could not be provided to secure the barrel in position. Malleable ball handles were used to replace the hand knobs. Because of the configuration of the ball handles, two hands can be used to tighten them, providing enough holding torque to keep the launcher barrel in position.

* Spacers - Spacers are used to seperate the tilt guide plates from the base support up-rights and provide a bearing surface for the tilt guide plates to slide on. Because the launcher tilt angle is adjusted frequently, the spacers should be either be re-fabricated in teflon or brass or used in combination with teflon or brass washers.

* Base Support/Stand - The base support for the launcher was designed to be strong and simple. However, weight reduction through design optimization is recommended.

* Barrel Weldment - The barrel design should be modified to incorporate carrying handles. Installation and removal of the barrel requires use of a strap wrench. The handles could also be used to apply the required torque during barrel installation and removed.

* Travel stops - Travel stops should be incorporated to prevent the Universal Launch System from rotating laterally to positions not designed to withstand recoil loads.

* Angle Indicators - Angle indicators (scribe lines, etc) should be added to indicate both lateral position and angle of incline.

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VII. APPENDICES, TABLES AND FIGURES

APPENDIX A Derivation for maximum height and range of a trajectory based on the mu velocity, Vo, and the launch angle, θ.

Equations of projectile motion in horizontal and vertical motion:

<u>HORIZONTAL MOTION</u>

NOTE $A_x = 0$

$\xrightarrow{+} V = Vo + A_c t;$	$V_x = Vo_x$	<1>
$\xrightarrow{+} S = So + Vot + (1/2)\, A_c t^2;$	$S_x = So_x + Vo_x t$	<2>
$\xrightarrow{+} V^2 = Vo^2 + 2A_c\, (S-So);$	$V_x^2 = Vo_x^2$	<3>

<u>VERTICAL MOTION</u>

NOTE: $A_y = -g$

$\uparrow V = Vo + A_c t;$	$V_y - Vo_y - gt$	<4>
$\uparrow S - So + Vot + (1/2)\, At^2;$	$S_y - So_y + Vo_y t - (1/2)\, gt^2$	<5>
$\uparrow V^2 = Vo^2 + 2\, A\, (S-So);$	$V_y^2 = Vo_y^2 - 2\, g\, (S_y - So_y)$	<6>

Given the mu velocity, Vo, and the launch angle, θ, calculate the height, S_y, and range, S_x, of the trajectory.

NOTE: Neglect the height of the cannon.

For S_y use equation <6>, $V_y^2 = Vo_y^2 - 2g\,(S_y - So_y)$ at the maximum height of the trajectory, the vertical velocity, $V_y = 0$. Also the initial height of the projectile, $So_y = 0$. Thus equation <6> reduces to:

$$0 = Vo_y^2 - 2\, g\, (S_y - 0) \quad \text{or} \quad S_y = \frac{Vo_y^2}{2g}$$

But, $Vo_y = Vo \sin \theta$

Thus, $S_{ymax} = \dfrac{(Vo \sin \theta)^2}{2g}$ <6a>

to determine the range of the trajectory, S_x, the flight time, t, must first be calculated $t = t_1 + t_2$ where t_2 = time for projectile to fall from S_{ymax} and t_1 = time for projectile to reach S_{ymax}.

From equation <4>, $V_y = Vo_y - gt$

$$t_1 = \frac{V_y - Vo_y}{-g} = \frac{0 - Vo_y}{-g} = \frac{Vo_y}{g}$$

since $Vo_y = Vo \sin \theta$ and $V_y = 0$ when $S_y = S_{ymax}$;

$$t_1 = \frac{Vo \sin \theta}{g} \qquad \text{<4a>}$$

from equation <6a> we know what S_{ymax} is, we also know $So_y = 0$. From equation 5,
$S_y = So_y + Vo_y\, t - (1/2)\, gt^2$ can be reduced to;

$S_{ymax} = 0 + (Vo \sin \theta)\, t - (1/2)\, gt^2$. Further deduction yield

$$\frac{(Vo \sin \theta)^2}{2g} = Vo \sin \theta t - (1/2)\, gt^2 \text{ or}$$

$$(1/2)\, gt^2 - (Vo \sin \theta)t + \frac{(Vo \sin \theta)^2}{2g} = 0$$

using the quadratic formula yields

$$t_2 = \frac{Vo \sin \theta}{g} \qquad \text{<4b>}$$

Finally the total flight time

$$t = t_1 + t_2 = \frac{Vo \sin \theta}{g} + \frac{Vo \sin \theta}{g} \text{ or}$$

$$t = \frac{2\, Vo \sin \theta}{g} \qquad \text{<4c>}$$

Utilizing the result of equation <4c>,

$t = \dfrac{2Vo \sin \theta}{g}$, equation <2>, $S_x = So_x + Vo_x t$, (where $So_x = 0$)

and $Vo_x = Vo \cos \theta$, yields:

$$S_x = 0 + Vo \cos\theta \frac{(2\,Vo \sin\theta)}{g}$$

$$\text{or } S_{xmax} = \frac{2\,Vo^2 \sin\theta \cos\theta}{g} \quad \text{<2a>}$$

SAMPLE CALCULATION:

Given : $Vo = 75$ m/s and $\theta = 55°$

Find : S_x @ S_{ymax} and S_{ymax} in units of feet

$$S_{ymax} = \frac{(Vo \sin\theta\,)^2}{2g}$$

$$= \frac{(75 \times \sin 55)^2}{2 \times 9.81} = 192.4 \text{ m} \times \frac{3.281 \text{ ft}}{\text{m}} = \underline{\textbf{631.2 feet ans.}}$$

$$@\ S_{ymax},\ S_x = So_x + Vo_x\, t_1 \quad \text{Where } So_x = 0,\ Vo_x = Vo \cos\theta$$

$$= \text{and } t_1 = \frac{Vo \sin\theta}{g} \quad \text{<4a>}$$

$$:\ Sx = \frac{Vo \sin\theta\ Vo \cos\theta}{g} = \frac{Vo^2 \sin\theta \cos\theta}{g} = \frac{S_{xmax}}{2}$$

$$\text{Thus:} Sx = (1/2)\ \frac{2 \times 75^2 \sin 55 \times \cos 55}{9.81} = 269.4\text{m}\ \frac{3.281 \text{ ft}}{\text{m}} =$$

883.9 feet ans.

APPENDIX B Calculation of height when the projectile was 450 feet down range during launch no 5.

Given: Vo, θ, and S_x;

Find: S_y

$$Vo = 75\ m/s \times \frac{100\ cm}{m} \times \frac{1\ in}{2.54\ cm} \times \frac{1\ ft}{12\ in} = 246\ ft/s$$

$\theta = 55°$

$Vo_x = Vo \cos\theta = 246 \cos 55° = 141.1$ ft/s

$S_x = 450$ feet;

$Vo_y = Vo \sin\theta$
$= 246 \sin 55° = 201.6$ ft/s

from eq <2> in appendix A: $S_x = So_x + Vo_x t$

$$t = \frac{S_x - So_x}{Vox} = \frac{450 - 1}{141.1} = 3.19\ sec$$

This is the time required to reach a range $S_x = 450$ ft + →

The height can be determined by substituting this time, t = 3.19 sec., into eq <5> from Appendix A $S_y = So_y + Vo_y t - (1/2)\ gt^2$.

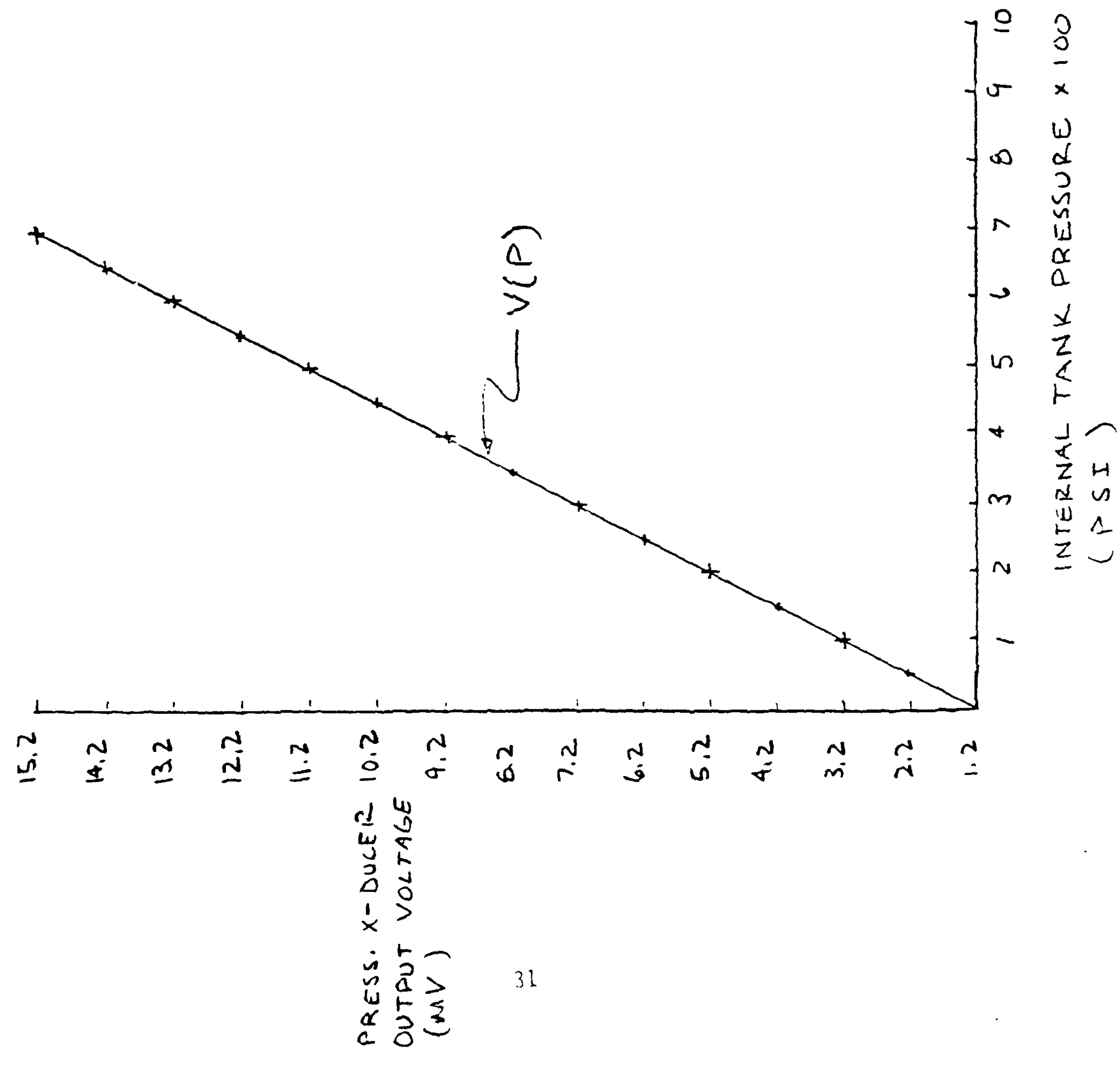
: $S_y = 0 + 201.6 \times 3.19 - (1/2) \times 32.2 \times (3.19)^2 =$ **479.3 ft +↑ ans.**

APPENDIX C

PLOT OF PRESSURE TRANSDUCER OUTPUT VOLTAGE
VS. INTERNAL TANK PRESSURE

NOTE: $V = 0.02P + 1.2$; $1.2 < V < 101.2$ mV

PRESSURE = P (PSI)
VOLTAGE = V (mV)



LATERAL ROTATION RANGE

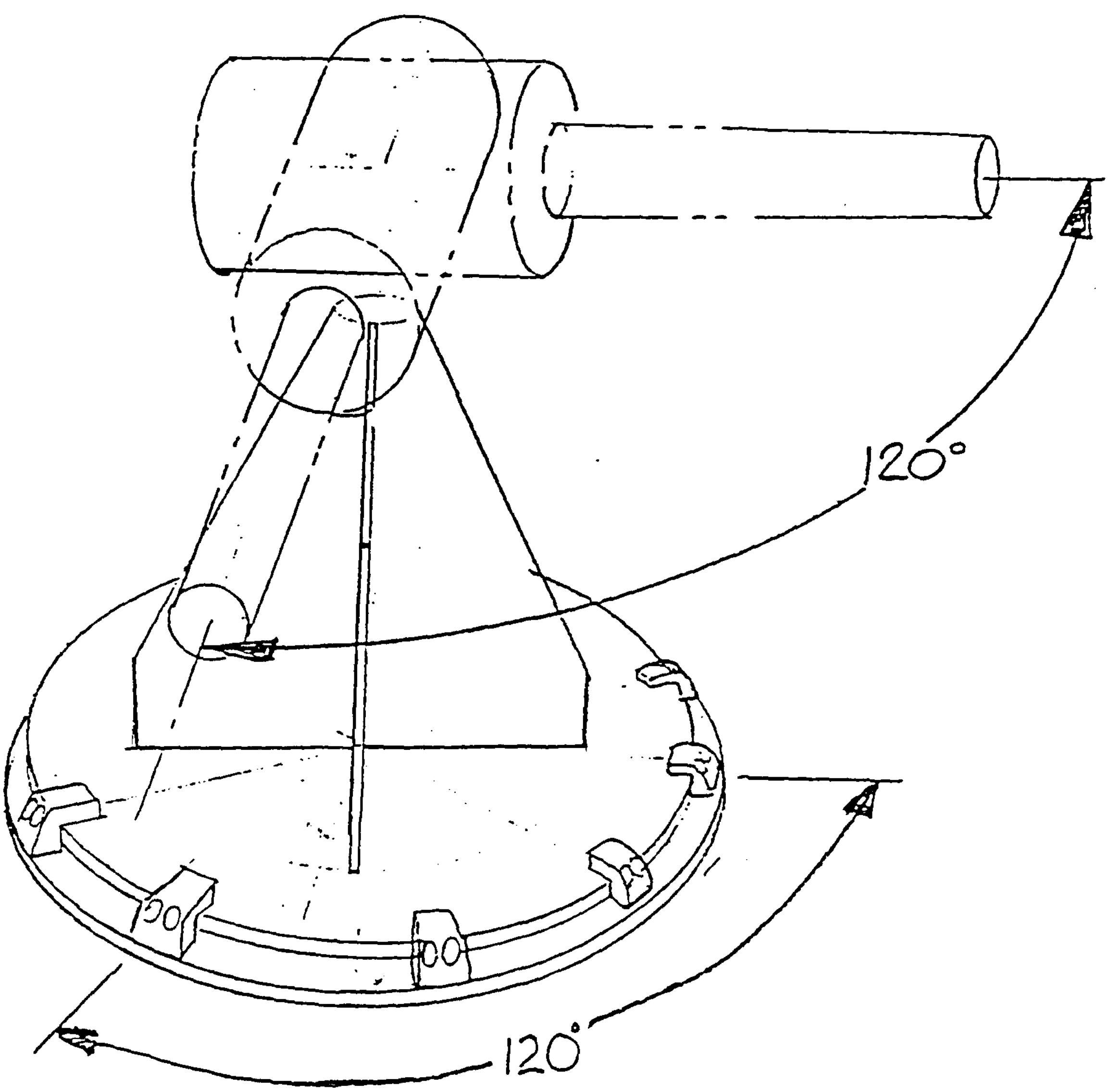


FIGURE 1

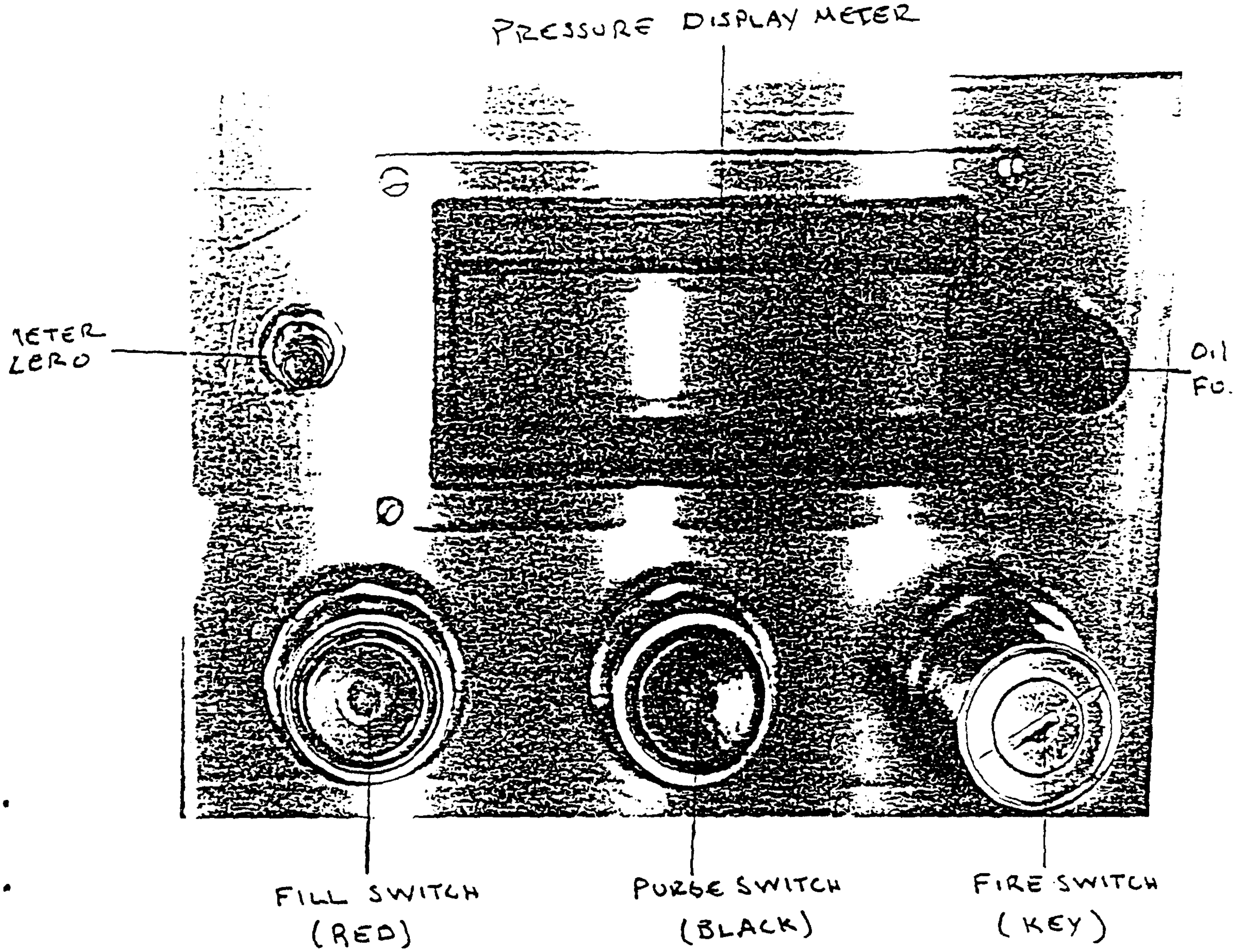
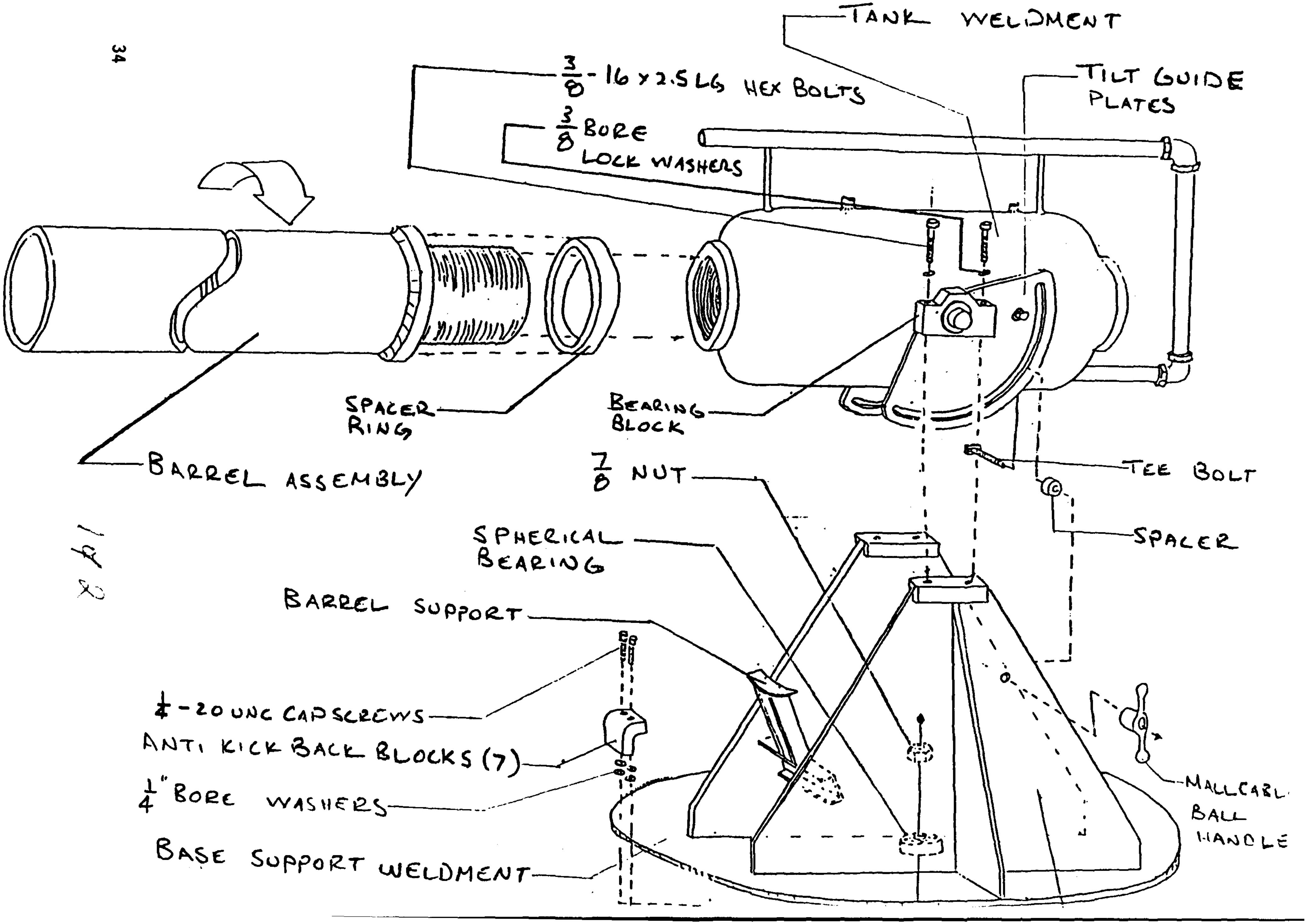


FIGURE 2: LAUNCHER CONTROL PANEL


TANK WELDMENT
3/8 - 16 x 2.5 LG HEX BOLTS
3/8 BORE LOCK WASHERS
TILT GUIDE PLATES
SPACER RING
BEARING BLOCK
BARREL ASSEMBLY
7/8 NUT
TEE BOLT
SPACER
SPHERICAL BEARING
BARREL SUPPORT
1/4 - 20 UNC CAPSCREWS
ANTI KICK BACK BLOCKS (7)
1/4" BORE WASHERS
BASE SUPPORT WELDMENT
MALLEABLE BALL HANDLE

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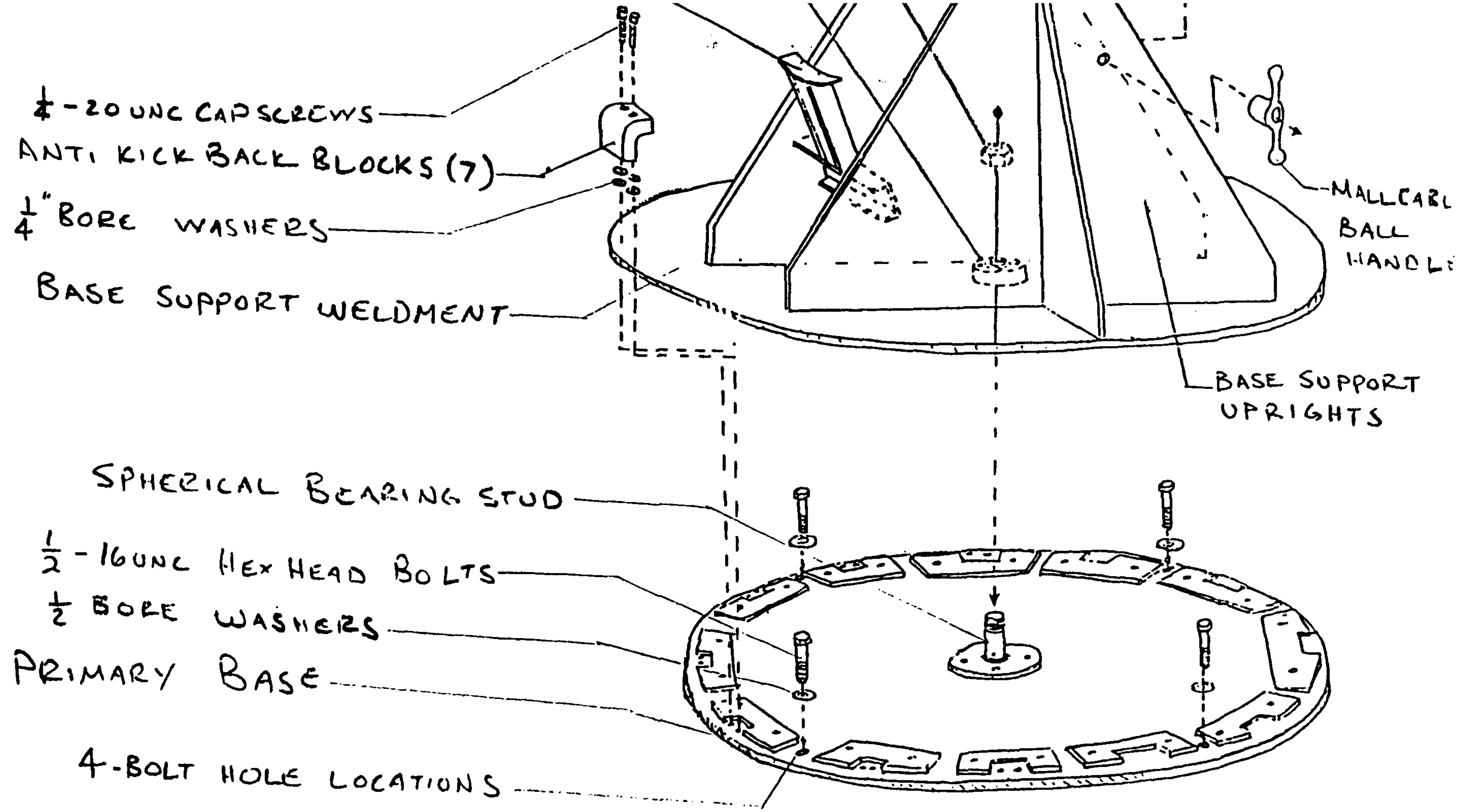

FIGURE 3: LAUNCHER ASSEMBLY